

**ELECTROCARDIOGRAM ANALYSIS
BY THE
BECKMAN INTEGRATED COMPUTING SYSTEM**

Beckman

COMPUTER OPERATIONS

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I. SUMMARY

The electrocardiogram is a valuable tool in assisting the doctor in his diagnosis of coronary disease. Current procedures require the doctor to be skilled in reading and interpreting these electrocardiograms, with analysis primarily based on visual examination and comparison with previous and/or "normal" ECGs.

To free the doctor from much of the time-consuming visual analysis and at the same time provide a more thorough examination at less expense to the patient, analysis of the electrocardiogram by an integrated analog-digital computer is proposed. Each part of the integrated computer would be used to accomplish the task for which it is best suited--the analog section to process and analyze the data and the digital section to diagnose the results. For a purely digital machine to perform this same task in a comparable length of time would require a considerably more expensive installation. With a hybrid computer available at a central laboratory the family doctor could analyze electrocardiograms as routinely and inexpensively as he now takes blood samples.

II. INTRODUCTION

The amount of information about the heart that can be gleaned from the electrocardiogram is impressive. Use of this tool could be extended and its expense reduced if the doctor did not have the time-consuming task of visually examining each cardiogram. This factor is particularly important when large numbers of such graphs are to be analyzed for statistical studies.

In the past digital computers have been used to analyze ECGs. This offers the obvious advantage of having the input data as a readily referenced, statically stored time series. The programmer can then, in affect, retrace the data and refer to it numerous times during a decision process. The data can be pre-edited and different decision criteria can be applied a second time to account for all possible variations in the data. However, the all-digital program is slow and expensive because the nature of the input data is not the type desired.

Consider such a program being demonstrated on the hybrid computer--the computation of the variability of the electrocardiogram. The original data is a multi-channel electrocardiogram which can be recorded on an instrumentation-type tape recorder or fed directly into the analog subsystem of the computer. The desired input data for the diagnostic program is a digital listing of the amplitudes and durations of the component waves of each beat of the cardiogram. A comparison of the information content of the input data with that desired will give an indication of the mass of data being handled unnecessarily in a pure digital machine. The input data is an analog signal with a frequency range of 0.1 to 100 cps and a desired resolution of 0.1 percent. Using these specifications, one minute of single-channel cardiogram would represent about 600,000 bits of information. Since the desired information consists of 15 data values per beat or approximately 20,000 bits, only about 5 percent of the input data is actually needed. If 95 percent of the input data to the digital machine can be eliminated, there are the obvious advantages of a simplified digital program and a speedup in the processing time.

The analog computer is a dynamic device with limited storage capabilities and is therefore essentially a one-pass data processor. However, it is ideally suited for processing large quantities of time-variant data such as the electrocardiogram which is really an analog signal. Thus it is logical to program the electrocardiogram analysis on a hybrid computing machine.⁽³⁾ The desired data is extracted by the analog section of the hybrid computer and sent to the digital section for storage and analysis. The problem can then be solved in the most efficient manner using each section of the hybrid machine to accomplish those tasks for which it is best suited.

III. A BRIEF DESCRIPTION OF THE HEART AND THE ELECTROCARDIOGRAM ANALYSIS

The heart is a muscular pump of marvelous efficiency.^(1, 2) Even during sleep the heart pumps some two ounces of blood with each beat, nearly five quarts per minute or 75 gallons per hour. When an individual is moderately active the heart doubles its output, and during strenuous exercise the heart's output may reach 14 barrels per hour. The heart is really a double pump, each side of which consists of an antechamber, called the atrium, and a ventricle. The right heart pumps used blood from the veins to the lungs via the pulmonary artery. There the blood discharges some carbon dioxide and absorbs oxygen. Then, traveling through the pulmonary veins to the left heart, the blood is pumped out through the aorta to all parts of the body. The ventricles fill up with blood from the atria which act mainly as reservoirs. The muscular walls of the ventricles cause most of the pumping action.

The pacemaker that causes the heart muscle to maintain its rhythmic beat is located in the heart itself. Just before each heart contraction a low intensity electrical impulse is initiated in a small knot of tissue on the rear wall of the right atrium called the sino-atrial or S-A node. This impulse travels over the atria exciting the muscle fibers to produce contraction of the atria. It also reaches another tissue knot called the atrio-ventricular or A-V node where the impulse is delayed about seven hundredths of a second before traveling through the ventricles and causing them to contract. Electrical currents generated by these impulses spread from the heart into surrounding tissue and then to the surface of the body. An electrocardiogram is a recording of these electrical potentials generated by the heart and is obtained by placing electrodes on the body on opposite sides of the heart. For the standard electrocardiogram, there are three electrical connections--to the two arms and the left leg. Changes in the heart can cause abnormal electric currents and thus alter the shape of the electrocardiogram. Thus the ECG becomes an important tool in detecting abnormalities of the heart.

Examination of the normal electrocardiogram shows that there are five waves (P, Q, R, S, T) associated with each heart beat (Fig. 1). The spacing between these waves and between heart beats is a function of heart rate. Normal heart rates vary from 40 to 120 per minute and the P, Q, R, S, and T waves are from 0.0600 to 0.0300 seconds in total duration followed by an isoelectric or baseline period of inactivity.⁽⁴⁾ The P wave is caused by electrical currents generated as the atria depolarize prior to contraction. The three waves known as the QRS complex are caused by currents generated when the ventricles depolarize before contraction. The T wave is caused by currents generated as the ventricles recover from the states of depolarization and is known as a repolarization wave.

In disease conditions the P wave can be irregularly, regularly, or randomly associated with the Q, R, S, and T waves; the P wave may even overlap with the other waves. Q, R, S, and T waves are always closely associated though they can be distorted. Irregular rhythms and unusual variance of wave shapes must be detected as abnormal by the computer, but it is not necessary that they be identified by diagnostic category. The five waves described may thus vary in amplitude and duration and a series of waves may vary in frequency. These parameters--amplitudes, duration, and frequency--form the essential basis for the electrocardiographic knowledge about the position and state of the heart. In the particular program being demonstrated, the following parameters are measured for each cardiogram lead: Amplitudes of P, Q, R, S, T, and average of ST; durations of PR, Q, QRS, QT and RR.

It should be pointed out that the electrical impulse to be measured on the cardiogram is in reality a vector and the three standard cardiograms taken are measurements of two components of the vector. In a normal heart the average direction of the heart vector during spread of the depolarization wave (mean electrical axis of the ventricles) is approximately 59 degrees (measured clockwise in the frontal plane with the zero vector taken as horizontal and directed toward the individual's left side). The problem of determining the average direction and amplitude of this vector is complicated by the fact that the heart position varies in different individuals and is somewhat dependent upon their build. It can be as low as 20 degrees or as high as 90 degrees and still indicate a normal heart. On the other hand, many pathologic conditions of the heart can shift the axis much more than this amount.

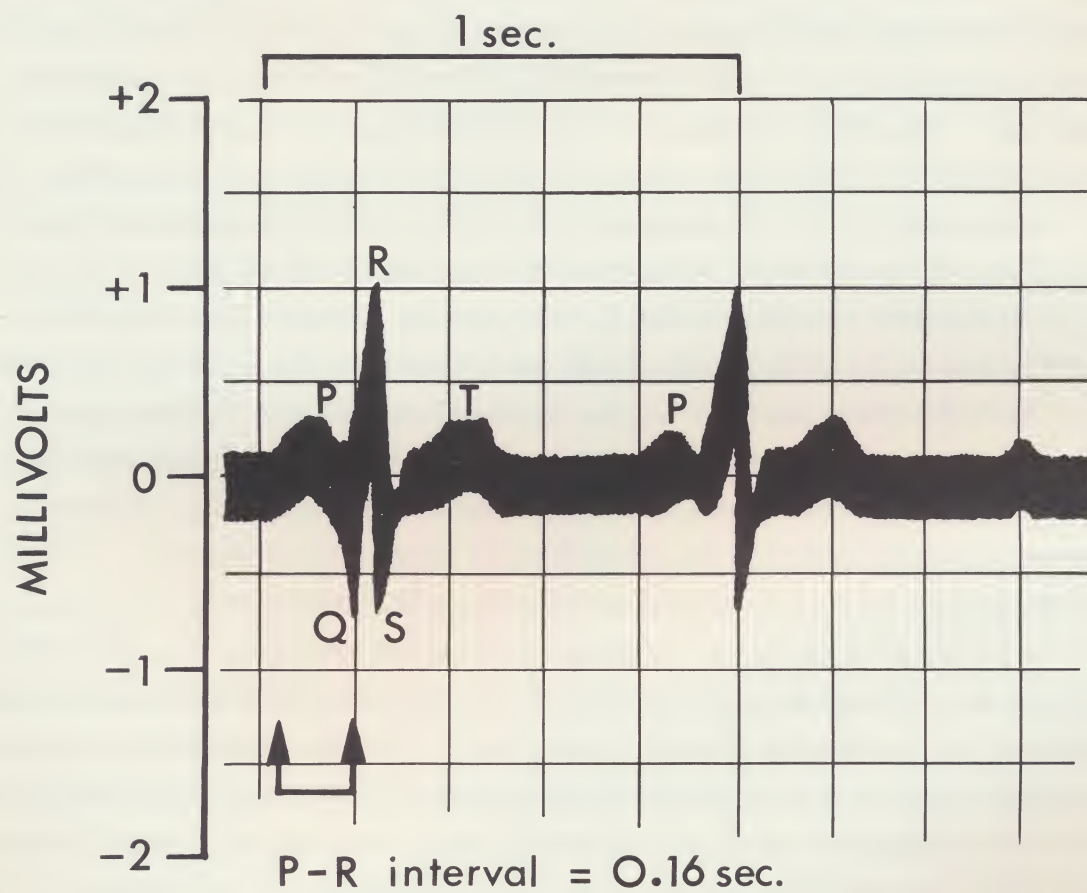


Figure 1. The Normal Electrocardiogram.

IV. PROGRAM ANALYSIS

The program for carrying out the electrocardiogram analysis on the hybrid computer can be broken down into three main sections:

- (1) Extraction of the required information from the input data by the analog section and transmission to the digital section of the hybrid machine;
- (2) the diagnostic analysis of these measurements by the digital section; and
- (3) the upgrading of the diagnostic parameters through analysis of the characteristics of the normal ECGs examined.

As mentioned in the previous discussion, eleven different wave amplitudes and durations for each cardiogram lead are to be measured by the analog and transmitted to the digital section in this demonstration program. The block diagram for this part of the program is given in Figure 2. The input data from the three electrocardiogram leads is fed into the analog section to a signal combination and resolution circuit. There the voltages are resolved into a total wave along the major axis of the heart. Use of this total wave assures that the signal used to locate the wave peaks is essentially free of variation caused by heart orientation.

By means of appropriate switches, information can be taken from any of the three leads or from the total wave. For demonstration and information purposes, these various waves can also be displayed on the polar scope.

The total wave and its approximate derivatives are used to synchronize and gate the analog measurement of wave durations and peaks. The basic logic signals for this analysis are obtained from comparators. The patch logic gates are used to combine these basic logic signals for the purpose of controlling the analog computing channels by means of electronic switches and relay drivers. Some of the logic level changes are used to interrupt the digital section and cause entry into data transfer subroutines. Logic levels are communicated to these subroutines by the test lines which may be patched on the logic board. Logic level changes are made on the basis of signals from the digital computer section. Hybrid FORTRAN II recognizes the statements CALL SIGNAL (n) and TEST (n). The statement CALL SIGNAL (n) causes a pulse on signal line n. The statement I - TEST (n) makes the FORTRAN integer argument I equal to 0 or 1, depending upon whether the logic level patched into test line n is false or true, respectively.

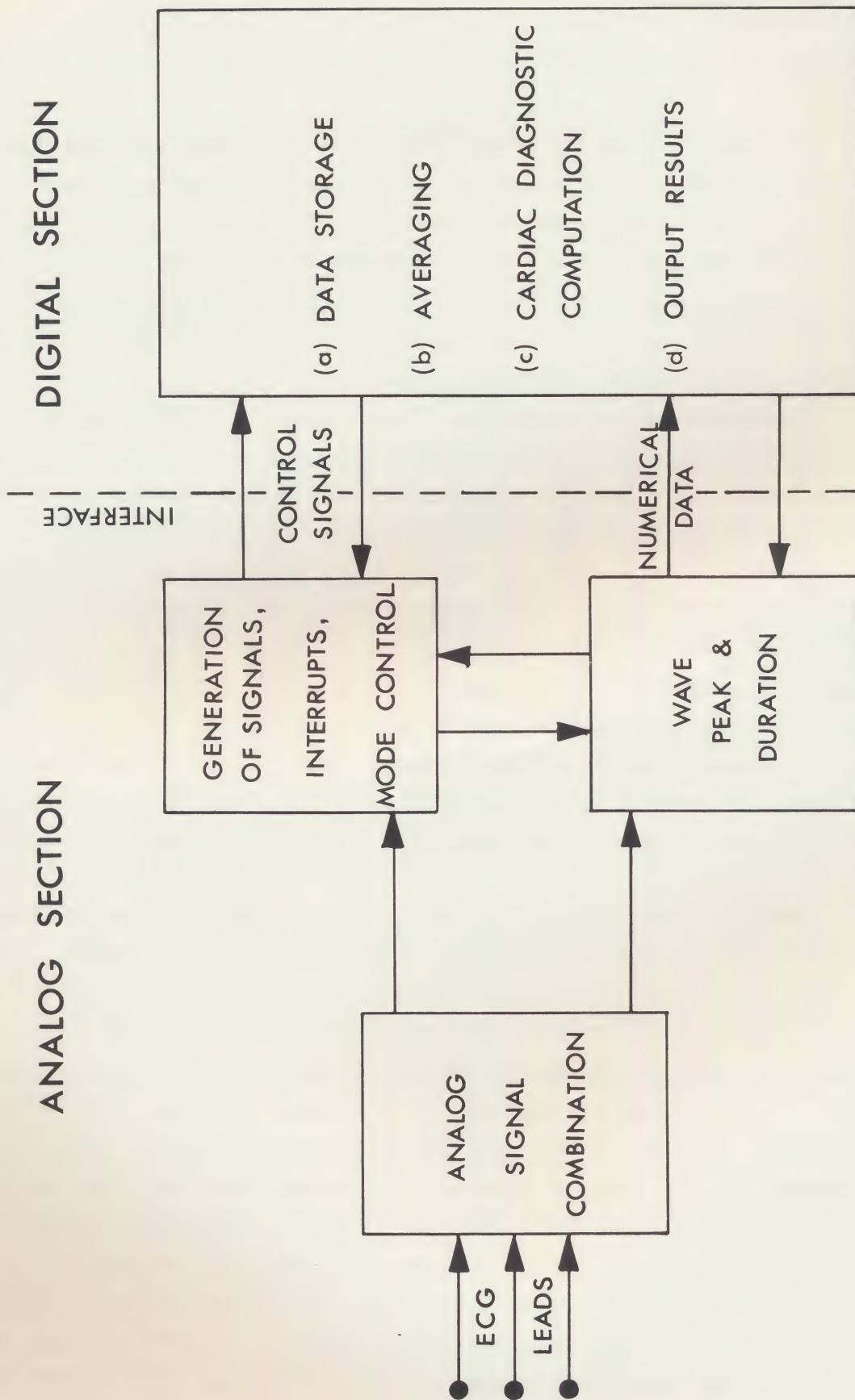


Figure 2.

V. APPENDIX 1

A. THE PEAK FOLLOWER CIRCUIT

The peak follower circuit is an important circuit in the extraction of data from the ECG leads. It is essentially a storage and comparison circuit whose input is controlled by an electronic gate. When this gate is open the circuit compares the input voltage with that already stored and continuously stores the larger of the two values. Thus the output of the peak follower is the highest input voltage applied while the gate is open (Fig. 3). The peak follower gate is controlled by logic signals from the digital section. The read cycles are triggered by interrupts from the analog comparators. The derivative changes sign and indicates a local peak. The output of the peak follower is read into the digital section through an analog-to-digital link (ADL).

Since it takes some time to clear the peak follower circuit after its information has been read, these circuits are used in pairs--one reading while the other clears. In the ECG analysis two pairs of peak followers are used, one pair to record positive peaks of the P, R, and T waves and the other pair to record the negative peaks of the Q and S waves.

Before the information from the peak follower can be read into the digital section, it is necessary to determine which pair is reading. This is accomplished by a digital subroutine started by a logic signal from one of the comparators. This subroutine first tests the peak follower to see which one is following; then reads the ADL from the one that is following and stores the information in the proper location in the digital memory. Next, the peak follower pair is toggled to clear one and start the other following. The final step is to increase the memory location index for storage of the next peak value.

B. USE OF ANALOG COMPARATORS IN THE ANALYSIS OF WAVES

The comparator is an electronic circuit designed to provide outputs--one of two fixed voltages corresponding to the logic states true and false.

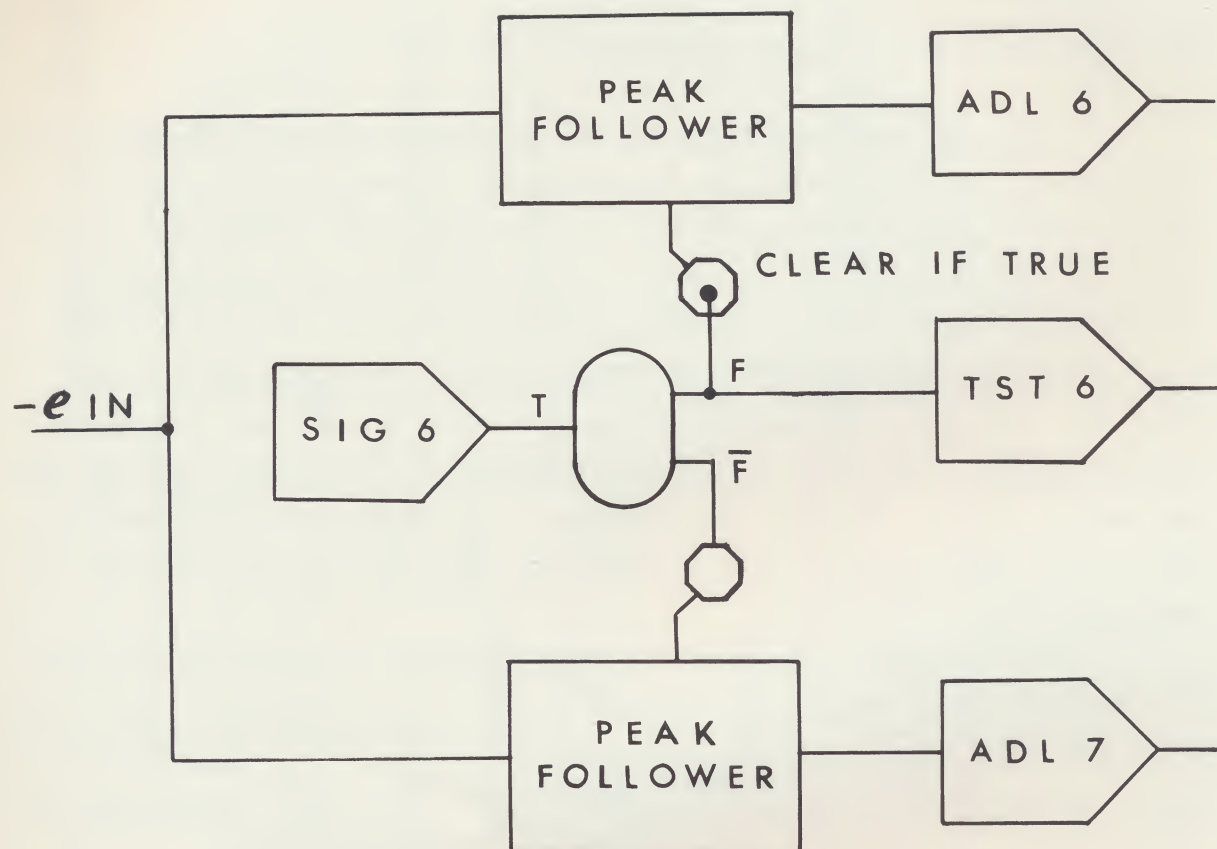


Figure 3. Peak Follower Circuit.

Two voltages are fed into the comparators--one a reference voltage and the other which is to be measured or compared. As long as the variable signal is less than the reference, the comparator indicates the logic state false; and when the signal is greater than the reference, the output is true.

A number of these comparators are used on the main wave and its derivatives to generate the control signals. Since the R wave is the largest and easiest to detect it is used as the trigger signal. One comparator is set high enough to give a true signal only during an R wave. Two other comparators on the main wave are set as low as possible ($\pm$ threshold) without being triggered by noise, and the reference voltage on the fourth is set at zero. In addition, two comparators are triggered by the approximate derivative, one by the absolute value of the derivative, and another by the analog clock. These logic levels are used to drive the control logic. When the first comparator is triggered by the R wave, its true signal generates an interrupt that starts the computation. The durations of time between events in the cardiac cycle are measured by switching analog integrators from hole to compute on the basis of logic signals. Between the T wave and the P wave the measurements are stored in the digital section through the ADL. The integrators are then cleared in the initial condition mode and the zero reference is defined.

The data in the digital section can be either a running average of the input data or a set of the beat parameters may be stored. The averages and variances (either running or for the set) are compared with nominal parameters obtained from normal wave forms. The results of this comparison provide information about the heart performance. The data obtained from these measurements can also be used to accumulate actuarial tables, provided the computer is supplied with the proper heart classification. In the demonstration program sample diagnostic type outs are provided to indicate the system capability.

VI. APPENDIX 2, HYBRID FORTRAN II SEQUENCE

```

# 1  *   HYBRID CARDIAC ANALYSIS
# 2  C   THE MAIN PROGRAM IS A MONITOR FOR THE VARIOUS SUBROUTINES.
# 3  *
# 4      DIMENSION DATA[14,0/10],TP[8,0/10]
# 5      DIMENSION NEX[0/3]
# 6      DIMENSION CG[11,0/4],CL[11,0/4]
# 7      DIMENSION AVGD[14],VARD[14]
# 8      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
# 9  C   SENSE SWITCH ONE IS USED TO INDICATE THAT NO
# 10 C   CHANGE IN DIAGNOSTIC PARAMETERS IS REQUIRED.
# 11      IF[SENSE SWITCH 1] 500,30
# 12      30 CONTINUE
# 13      DO 20, I#0,3
# 14      READ 8, [CG[J,I], J#1,11]
# 15      READ 8, [CL[J,I], J# 1,11]
# 16      20 CONTINUE
# 17  C   SUBROUTINE SET UP INITIALIZES THE COMPUTER BY
# 18  C   SETTING ANALOG POTENTIOMETERS AND DIGITAL INDEXES.
# 19      500 CALL SET UP
# 20  C   THE SUBROUTINES PEAK,RWAVE,AND READ DATA
# 21  C   ARE ENTERED WHEN AN INTERRUPT IS RECEIVED FROM
# 22  C   THE ANALOG SECTION. THE STATEMENTS CALL PEAK[5,FINT[1]] AND
# 23  C   CALL PEAK[6,FINT[2]] ATTACH THE SUBROUTINE PEAK TO
# 24  C   INTERRUPTS ONE AND TWO. THE PARAMETER[5 OR 6] INDICATES
# 25  C   WHICH INTERRUPT IS BEING SERVICED.
# 26      CALL RWAVE[FINT[0]]
# 27      CALL PEAK[5,FINT[1]]
# 28      CALL PEAK[6,FINT[2]]
# 29      CALL READ DATA[FINT[4]]
# 30      CALL TYPE IN
# 31      CALL COMPUTE
# 32  C   PUTS ANALOG SECTION IN THE COMPUTE MODE.
# 33      2 IF[TEST[14]] 2,2,3
# 34      3 CALL INT ENABLE
# 35  C   CHOICE OF RUNNING AVERAGE OR SET OF INDIVIDUAL MEASUREMENTS
# 36      IF[NLEAD]201,201,200
# 37      200 CONTINUE
# 38      4 IF[SENSE LIGHT 1] 5,4
# 39      5 CALL DATA REDUCTION
# 40      GO TO 402
# 41      DO 333 I # 1,14

```

```

#      #      42      333 VARD[I] # 0
#      43      201 CALL RUN AVERAGE
#      44      402 CALL TYPE OUT
#      45      CALL CARDIAC COMPARISON
#      46      C      CARDIAC DIAGNOSTIC ROUTINE COMPARES MEASURED
#      47      C      PARAMETERS TO THE VALUES DESIRED BY THE
#      48      C      CARDIOLOGIST. THE AUTOMATIC MEASUREMENTS
#      49      C      CAN ALSO BE USED TO DEVELOP ACTUARIAL
#      50      C      INFORMATION. IN THE DEMONSTRATION
#      51      C      THE STANDARD PARAMETERS ARE APPROXIMATE
#      52      C      AND THE DIAGNOSTIC COMMENTS FRIVOLOUS. HERE
#      53      C      THEIR PURPOSE IS TO DEMONSTRATE THE MACHINE
#      54      C      CAPABILITY.
#      55      GO TO 500

```

```

#      56      8 FORMAT[6E13.5]
#      57      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

```

00021 I      00022 J

```

SUBPROGRAMS REQUIRED

SETUP	RWAVE	FINT	PEAK	READDATA	TYPEIN
COMPUTE	TEST	INTENABL	DATAREDU	RUNAVERA	TYPEOUT
CARDIACC					

THE END


```

#      1      *      SET UP
#      2      SUBROUTINE SET UP
#      3      DIMENSION AVGD[14], VARD[14]
#      4      DIMENSION DATA[14, 0/10], TP[8, 0/10]
#      5      DIMENSION NEX[0/3]
#      6      DIMENSION CG[11, 0/4], CL[11, 0/4]
#      7      DIMENSION POT[0/49]
#      8      COMMON N, NP, M, NLEAD, A, IXFR, NEX, TP, DATA, AVGD, VARD, CG, CL
#      9      A#-0.6
#     10      NP#1
#     11      N#0
#     12      IXFR#3
#     13      DO 7, I#0, 3
#     14      7 NEX[I]#0
#     15      IF[SENSE SWITCH 1] 5, 6
#     16      6 CONTINUE
#     17      CALL SET POT[4, .5, 1., .5, 1.]
#     18      CALL ADL[14, B2, 57.3, BV, 57.3]
#     19      DO2, K#0, 3
#     20      2 CALL SET POT[K, .05, 1.]
#     21      POT[12]#.90
#     22      POT[30]#COS[B2]/SIN[B2]
#     23      POT[31]#1.0/[2.0*SIN[B2]]
#     24      POT[14]#COS[BV]
#     25      POT[15]#SIN[BV]
#     26      POT[24]#.5
#     27      POT[36]#.3
#     28      POT[37]#.01
#     29      POT[38]#.01
#     30      POT[39]#.01
#     31      POT[40]#.01
#     32      POT[41]#.2
#     33      POT[13]#.4
#     34      DO 3, K#12, 15
#     35      3 CALL SET POT[K, POT[K], 1.]
#     36      CALL SET POT[30, POT[30], 0.1, POT[31], .1]
#     37      CALL SET POT[24, POT[24], 1.]
#     38      DO4, K#36, 41
#     39      4 CALL SET POT[K, POT[K], 1.]
#     40      5 CONTINUE
#     41      CALL CLEAR
#     42      CALL STAND BY
#     43      RETURN
#     44      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

00010 POT
00160 B2

00154 I
00162 BV

00155 K

00156 SETUP

SUBPROGRAMS REQUIRED

SETPOT

ADL

COS

SIN

CLEAR

STANDBY

THE END

```
# 1      SUBROUTINE TYPE IN
# 2      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
# 3      5  FORMAT[// $NUMBER OF BEATS$]
# 4      TYPE 5
# 5      15 FORMAT[I2]
# 6      ACCEPT 15,M
# 7      25 FORMAT[// $LEAD IDENTIFICATION$]
# 8      TYPE 25
# 9      ACCEPT 15,NLEAD
# 10     TYPE 35
# 11     35 FORMAT[/ $THANK YOU$ ///]
# 12     RETURN
# 13     END
```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77770 NEX	77766 TP
77764 DATA	77762 AVGD	77760 VARD	77756 CG
77754 CL			

PROGRAM ALLOCATION

00000 TYPEIN

THE END


```

#      1  *      READ DATA
#      2      SUBROUTINE READ DATA
#      3      DIMENSION DATA[14,0/10],TP[8,0/10]
#      4      DIMENSION AVGD[14],VARD[14]
#      5      DIMENSION CG[11,0/4],CL[11,0/4]
#      6      DIMENSION NEX[0/3]
#      7      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
#      8      DO 2,I#2,6
#      9      CALL ADL [I,DATA[I,N], 50.]
#     10      2 CONTINUE
#     11      IF [TEST[7]]3,3,7
#     12      3 SENSE LIGHT 7
#     13      7 CONTINUE
#     14      IF[NP-6]5,4,6
#     15      6 NEX[NP-6]#NEX[NP-6]&1
#     16      GO TO 4
#     17      5 NEX[0]#NEX[0]&1
#     18      4 NP#1
#     19      SENSELIGHT 5
#     20      N#N&1
#     21      IXFR#3
#     22      IF[M-N] 8,31,31
#     23      31 RETURN
#     24      8 CALL POTSET
#     25      SENSE LIGHT 1
#     26      RETURN
#     27      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

00007 I 00010 READDATA

SUBPROGRAMS REQUIRED

ADL TEST POTSET

THE END

```

# 1 * TYPE IN
# 2 SUBROUTINE TYPE OUT
# 3 DIMENSION DATA[14,0/10],TP[8,0/10]
# 4 DIMENSION CG[11,0/4],CL[11,0/4]
# 5 DIMENSION AVGD[14],VARD[14]
# 6 DIMENSION NEX[0/3]
# 7 COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
# 8 TYPE 43
# 9 43 FORMAT[10X,$MEAN VALUES OF DURATIONS$]
# 10 TYPE 44
# 11 44 FORMAT[/4X,$R TO R$,7X,$P TO R$,7X,$Q WAVE$,9X,$QRS$,9X
# 12 1$QTO T$/]
# 13 TYPE 46,[AVGD[I],I#1,5]
# 14 46 FORMAT[5E13.5/]
# 15 47 FORMAT[/10X,$VARIANCE OF DURATIONS$/]
# 16 TYPE 47
# 17 TYPE46,[VARD[I],I#1,5]
# 18 48 FORMAT[10X,$MEAN VALUES OF MAGNITUDES$//]
# 19 TYPE 48
# 20 49 FORMAT[4X,$AVG ST$,7X,$PEAK P$,7X,$PEAK Q$,7X,$PEAK R$,7X,$PEAK S
# 21 1$,7X,$PEAK T$/]
# 22 TYPE 49
# 23 50 FORMAT[6E13.5/]
# 24 TYPE 50,[AVGD[I],I#6,11]
# 25 52 FORMAT[/ $VARIANCES OF MAGNITUDES$/]
# 26 TYPE 52
# 27 TYPE 50,[VARD[I],I#6,11]
# 28 54 FORMAT[/ $MISSING PEAKS$,15/]
# 29 TYPE 54,NEX[0]
# 30 56 FORMAT[$EXTRA PEAK DISTRIBUTION$/]
# 31 57 FORMAT[$ONE$,15]
# 32 TYPE 56
# 33 58 FORMAT[$TWO$,15]
# 34 59 FORMAT[$THREE$,15]
# 35 TYPE 57,NEX[1]
# 36 TYPE 58,NEX[2]
# 37 TYPE59, NEX[3]
# 38 60 CONTINUE
# 39 IF[SENSE SWITCH 4] 70,60
# 40 70 IF[SENSE SWITCH 3] 75,76
# 41 75 TYPE 80
# 42 80 FORMAT[/ $INDIVIDUAL DURATIONS$//]
# 43 TYPE 44
# 44 DO 77 K#1,M
# 45 77 TYPE 46,[DATA[I,K],I#1,5]
# 46 81 FORMAT[/ $INDIVIDUAL MAGNITUDES$/]

```

```

#      47          TYPE 81
#      48          TYPE 49
#      49          DO 78 K#1,M
#      50          78 TYPE 50, [DATA[I,K],I # 6,11]
#      51          76 RETURN
#      52          END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

```

00002 I          00003 K          00004 TYPEOUT
THE END

```



```

#      1  *      DATA REDUCTION
#      2  C      SUBROUTINE FOR FINDING THE MEANS AND VARIANCES OF CARDIAC DATA
#      3      SUBROUTINE DATA REDUCTION
#      4      DIMENSION DATA[14,0/10],TP[8,0/10]
#      5      DIMENSION CG[11,0/4],CL[11,0/4]
#      6      DIMENSION AVGD[14],VARD[14]
#      7      DIMENSION NEX[0/3]
#      8      DIMENSION X[14]
#      9      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
#     10      DO 10,I#1,14
#     11      AVGD[I]#0
#     12      VARD[I]#0
#     13      10 X[I]#0
#     14      DO 21, J#1,M
#     15      DO 20 I#1,14
#     16      AVGD[I]#AVGD[I]&DATA[I,J]
#     17      20 X[I]#X[I]&DATA[I,J]**2
#     18      21 CONTINUE
#     19      DO 30 I#1,14
#     20      AVGD[I]#AVGD[I]/M
#     21      X[I]#X[I]/M
#     22      30 VARD[I] # X[I] - AVGD[I]**2
#     23      TYPE 42,M
#     24      42 FORMAT[/13,$ BEATS$/]
#     25      RETURN
#     26      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

00002 X	00036 I	00037 J	00040 DATAREDU
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THE END

```

#      1  *      RUN AVERAGE
#      2      SUBROUTINE RUNAVERAGE
#      3      DIMENSION DATA[14,0/10],TP[8,0/10]
#      4      DIMENSION AVGD[14],VARD[14]
#      5      DIMENSION CG[11,0/4],CL[11,0/4]
#      6      DIMENSION NEX[0/3]
#      7      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
#      8      10 IF[SENSE LIGHT 5]20,10
#      9      20 DO 30 I # 1,14
#     10      IF [1-N] 24,22,22
#     11      22 AVGD[I] # DATA[I,1]
#     12      GO TO 30
#     13      24 AVGD[I] # [[M-1]*AVGD[I] & DATA[I,1]]/M
#     14      30 VARD[I] # [[M-1]*VARD[I] & [DATA[I,1] - AVGD[I]]**2]/M
#     15      N # 1
#     16      IF [SENSE SWITCH 3] 40,10
#     17      40 RETURN
#     18      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

00010 I 00011 RUNAVERA

THE END

```

#      1      *      RWAVE
#      2      SUBROUTINE RWAVE
#      3      DIMENSION DATA[14,0/10],TP 8,0/1 ]
#      4      DIMENSION CG 11,0/4],CL[11,0/4]
#      5      DIMENSION AVGD[14],VARD[14]
#      6      DIMENSION NEX[0/3]
#      7      COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
#      8      CALL ADL [1,XXX, 50.]
#      9      CALL DAL[1,XXX*A, 50.]
#     10      IF[N] 3,2,1
#     11      1 DATA[1,N]# XXX*2
#     12      RETURN
#     13      2 N#N&1
#     14      3 RETURN
#     15      END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 NLEAD
77772 A	77771 IXFR	77765 NEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

00004 RWAVE 00006 XXX

SUBPROGRAMS REQUIRED

ADL DAL

THE END


```

#      1  *      PEAK
#      2  C      PEAK READING SUBROUTINE FOR CARDIAC ANALYSIS
#      3          SUBROUTINE PEAK[LINE]
#      4          DIMENSION DATA[14,0/10],TP[8,0/10]
#      5          DIMENSION AVGD[14],VAR [14]
#      6          DIMENSION CG[11,0/4],CL[11,0/4]
#      7          DIMENSION NEX[0/3]
#      8          COMMON N,NP,M,NLEAD,A,IXFR,NEX,TP,DATA,AVGD,VARD,CG,CL
#      9          GO TO[1,1,3],IXFR
#     10          3 CALL ADL[2*LINE-3&ITEST[LINE],DATA[6&NP,N],.2E5]
#     11          CALL SIGNAL[LINE]
#     12          CALL ADL[11&ITEST[8],TP[NP,N],50.]
#     13          NP#NP&1
#     14          IF[NP-8] 1,1,2
#     15          1 RETURN
#     16          2 IXFR#1
#     17          RETURN
#     18          END

```

COMMON ALLOCATION

77777 N	77776 NP	77775 M	77774 MLEAD
77772 A	77771 IXFR	77765 MEX	77505 TP
77021 DATA	76765 AVGD	76731 VARD	76553 CG
76375 CL			

PROGRAM ALLOCATION

DUMMY LINE 00015 PEAK

SUBPROGRAMS REQUIRED

ADL ITEST SIGNAL

THE END

VII. APPENDIX 3, REFERENCES

1. Wiggers, Carl J.: The Heart; Scientific American, May, 1957; pp. 74-88
2. Guyton, Arthur C., M.D.; Textbook of Medical Physiology; W. B. Saunders Co., Philadelphia and London, 1961; Part V.
3. Zeitlin, Richard A.; Cady, Lee D.; Tich, Leo J.; Woodbury, Max A.; Combined Analog-Digital Processing of Cardiograms; New York University Medical Center and College of Engineering, Research Division, New York University, New York, N. Y.